SPECIFICATION

TITLE

"COMPUTER-ASSISTED DETECTION METHOD FOR DIAPHRAGM EDGES CAUSED IN AN IMAGE BY A DIAPHRAGM"

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention concerns a computer-assisted detection method for diaphragm edges caused in an image by a diaphragm, of the type wherein the image is provided to a computer, the computer detects image edges present in the image, and the diaphragm edges are determined from the detected image edges.

Description of the Prior Art

In particular in the acquisition of x-ray images, the radiation beam path is normally blocked or blocked at the outer edge with shielding elements – for example, lead plates or the like. The radiation exposure for the examined subject (usually a person) is thereby minimized, and irradiation and/or scattered radiation effects are at least partially reduced. Furthermore, the data quantity is reduced. This concerns both the storage of the image data and its reproduction and processing.

The shielding elements form a diaphragm. The inner edges of the shielding elements are the diaphragm edges. They normally form a polygon, usually a rectangle, but the rectangle does not always exhibit the same orientation.

Relevant image information is located only within the inner (unblanked) region defined by the diaphragm edges.

Naturally, it is possible to acquire and represent the entire image and then have a user scan the position of the diaphragm edges. For example, the user can plot these edge positions interactively in the displayed image, but this procedure is slow, laborious and error-prone.

Therefore, methods have been developed for computer-assisted detection of diaphragm edges by means of which the detection mentioned above is automatically possible. German OS -197 42 152, German OS 197 34 725 and United States Patent No. 5,351,306 disclose examples of such methods.

The known methods operate quite satisfactorily in the majority of application cases. Given disadvantageous conditions, in particular when large implants are located in the patient to be examined or when the diaphragm contrast differs too little from the patient contrast, the diaphragm edges, however, are not recognized as such. It is thus possible that no diaphragm edge recognition ensues at all or that edges in the image of the examination subject are incorrectly determined as the diaphragm edges.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a computer-assisted detection method with which the diaphragm edges can be detected with higher certainty, even under disadvantageous conditions.

The object is achieved in a method of the type initially described wherein, in addition to the image, information about the inner structure of the diaphragm is provided to the computer, and the computer determines the diaphragm edges from among all detected image edges using the information about the inner structure of the diaphragm.

When, for example, it is thus known that the diaphragm edges form a rectangle (or a regular hexagon), the computer can test whether, in addition to one image edge, a further image edge running in parallel and two (or four) further image edges exist that, with the first image edge, form an angle of 90° (or of +60° and − 60°). Only then can the first image edge be a diaphragm edge.

The detection of the diaphragm edges ensues in two main steps, namely with the detection of all image edges, as well with the determination of the diaphragm edges from among the image edges.

The image normally has a number of two-dimensionally disposed pixels, with a grey scale value that lies between minimal and maximal possible values is associated with each pixel. In this case, image edge determination proceeds by the computer detecting the image edges by determining derivative value for each pixel and detecting the images edges using the derivative values.

The computer can determine the derivative values as a sum of at least four summands, with each of the summands being comprised of a product of a derivative in a derivative direction and a weighting factor, and the computer determines the weighting factor specific to the derivative.

It is particularly advantageous in this case for the derivative directions to form direction pairs, with the derivative directions of each direction pair being aligned oppositely. The derivative directions of different direction pairs should form with one another an angle varying from 0° to 180°, in particular an angle of approximately 90°. When the image has main axes orthogonal to one another, the derivative directions can be parallel to the main axes.

Outside of the region defined by the diaphragm edges, the image ideally should have no variations whatsoever (realistically only slight variations). Significant jumps (= image edges) thus should occur either only within the gated region or at the crossover to the gated region, thus at the diaphragm edge itself. The computer therefore preferably reduces the derivative-specific weighting factor when it determines a derivative different from zero for an intermediate pixel arranged between the pixel under consideration and an initial pixel. The initial pixel thereby

lies on an edge of the image. A vector from the initial pixel to the pixel under consideration corresponds with the respective direction of derivative. With this procedure, image edges thus are weighted, in general, inversely to the size of the jumps that exist before the edge is detected to be present (larger jumps lower weighing).

Furthermore, negative jumps, thus jumps from high to low grey scale values, occur only within the gated region. Given equal magnitude of the derivative for the intermediate pixel, when the computer therefore reduces the derivative-specific weighting factor more significantly given a negative derivative for the intermediate pixel than given a positive derivative for the intermediate pixel, negative jumps lead to a particularly significant reduction of the weighting factor.

Dependent on the information about the inner structure of the diaphragm, the diaphragm edges can, for example, known angles with one another. In this case it is possible, as already mentioned, to detect the diaphragm edges by the computer detecting groups of detected image edges that, with one another, form at least one of the known angles.

When, according to the information about the inner structure of the diaphragm, two of the diaphragm edges run parallel to one another, the computer preferably assesses such image edges running parallel to one another as diaphragm edges only when the image edges running parallel to one another exhibit a minimum separation from one another. This reflects the fact that the diaphragm edges in practice always exhibit a minimum separation from one another.

The detection method works particularly reliably when the computer forms a sum value of the derivative values for the groups of image edges that, with one another, form at least one of the known angles and tests the groups image edges in

the series of the sum values, with the computer testing groups of image edges with larger sum values before groups of image edges with lesser sum values.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration of an x-ray examination apparatus operating in accordance with the inventive method, and employing a computer program with a computer programmed product according to the invention.

Figure 2 schematically illustrates an x-ray image obtained with the apparatus of Figure 1, for explaining the inventive method.

Figures 3 through 6 are flowcharts showing the basic steps of the inventive method and various embodiments thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The x-ray arrangement shown in Figure 1 has an x-ray source 1 and an x-ray detector 2. An image B of a subject 3 – for example a person 3 – is acquired by the x-ray arrangement and is supplied to a computer 4. The image B is evaluated by the computer 4, output to a user 5 and, as the case may be, also archived.

The image B is shown as an example in Figure 2. According to Figure 2, the image B has a number of pixels 6, 6', 6". The pixels 6, 6', 6" are two-dimensionally arranged relative to main axes x, y. The main axes x, y are orthogonal to one another. In the example of Figure 2, the image B has 512x512 pixels 6, 6', 6". Each pixel 6, 6', 6" exhibits a grey scale value that is between zero (minimum possible value) and, for example, 255 (maximum possible value).

X-ray radiation is ionizing radiation. In order to keep the radiation exposure of the subject 3 to a minimum, according to Figure 1 a diaphragm 7 is dispose in the beam path of the x-ray arrangement. Among other things, the diaphragm 7 causes

diaphragm edges 8 in the image B, in addition to image edges 9 caused by the subject 3.

According to Figure 2, the diaphragm edges 8 form, for example, a rectangle. Therefore, for any given diaphragm three further diaphragm edges 8 are present in the image B, independent of the arrangement and/or rotation of the diaphragm 7. One of these further diaphragm edges 8 runs parallel to the first cited diaphragm edge 8 and both other additional diaphragm edges 8 form an angle of 90° with the first cited diaphragm edge 8. This information about the inner structure of the diaphragm 7 can be used in order by the computer for detecting the diaphragm edges 8.

For automatic computer-assisted detection of the diaphragm edges 8, the computer 4 is programmed with a computer program 10 that is stored on a data medium 11, for example a CD-ROM 11 in (exclusively) machine-readable format. Based on the programming with the computer program 10, the computer 4 executes the detection method (subsequently described in detail) for the diaphragm edges 8.

According to Figure 3, in a step S1 the computer 4 first receives information about the inner structure of the diaphragm 7. In a step 2, it then receives the image B. In a step S3, the computer 4 then detects the image edges 8, 9 that are present in the image B. At this point in time, it is still unknown to the computer 4 which of the image edges 8, 9 are the diaphragm edges 8 it seeks. In a step S4, the computer 4 detects the desired diaphragm edges 8 from among the image edges 8, 9 using the information about the inner structure of the diaphragm 7.

The receipt of information about the inner structure of the diaphragm 7 and the receipt of the image B in the steps S1 and S2 requires no more detailed

explanation. The detection of the image edges 8, 9 and of the diaphragm edges 8 in the steps S3 and S4 is explained in more detail in Figures 4 through 6.

To detect the image edges 8, 9, according to Figure 4 in a step S5 the computer 4 first determines a first derivative A1 and a corresponding weighting factor W1 for each pixel 6, 6', 6" in a first derivative direction R1. The computer 4 also does this in second, third and fourth derivative directions R2 through R4 in steps S6 through S8. In a step S9, the computer 4 then determines for each pixel 6, 6', 6" a derivative value z' as a sum of the derivatives A1 through A4, with each of the summands A1 through A4 being weighted with its corresponding weighting factor W1 through W4.

The determined derivative value z' can then be tested by the computer 4 as to whether it exceeds (in terms of magnitude) a threshold. When this is the case, the corresponding pixel 6, 6', 6" is taken to be a component of an image edge 8, 9. Using the derivative value z', the computer 4 is thus able to detect the image edges 8, 9.

As can be seen from Figure 2, the derivative directions R1 and R2 form a direction pair of derivative directions R1, R2 aligned opposite to one another. The same is true for the derivative directions R3 and R4. The derivative directions R1 through R4 thereby preferably run parallel to the main axes x, y. In particular, the direction pairs form with one another an angle that is significantly different from 0° and 180°, in the present example equal to 90°.

There are various possibilities to detect the derivatives A1 through A4 and the corresponding derivative-specific weighting factors W1 through W4. A procedure is subsequently specified in connection with Figure 5 that has proven to be particularly

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reliable in tests. Only the step S7 from Figure 4 is explained in detail in Figure 5. The procedure with regard to steps S5, S6 and S8 is wholly analogous.

According to Figure 5, in steps S10 through S12 curve indices i, j and a derivative sum W are initially set to zero. In a step S13, the derivative A3 is then determined at the point (i,j) according to the formula

$$A3(i,j) = z(i,j+a) - z(i,j-b)$$

wherein a and b are non-negative offsets. One of the two offsets a, b may be zero, but at least one must be different than zero. The offsets a, b preferably assume the same value and/or lie between one and three.

In a step S14, it is tested whether the derivative A3 is larger or smaller than zero at the location (i,j). When the derivative A3 is larger than zero, the derivative sum W is increased by the derivative A3 in a step S15. Alternatively, the derivative sum W is increased by the square of the derivative A3 in a step S16.

In a step S17, the derivative-specific weighting factor W3 at the point (i,j) is then set equal to the reciprocal of the derivative sum W.

In steps S18 and S19, the curve index j is increased by one and tested as to whether it has already exceeded the value 511 (thus has arrived at the image edge). If this is still not the case, a return to step S13 is made. Alternatively, in steps S20 and S21 the curve index i is increased by one and likewise checked as to whether the curve index i has exceeded the value 511 (thus has arrived at the image edge). If this is still not the case, a return to step S11 is made. Alternatively, the determination of the derivative A3 and of the corresponding weighting factor W3 ends for the third derivative direction R3.

As already mentioned, other methods are possible for detecting the derivatives A1 through A4 and the derivative-specific weighting factors W1 through W4. However, the procedure according to Figure 5 exhibits the advantage that the computer 4 reduces the derivative-specific weighting factor W3 every time it comes up against an image edge 8, 9. The reduction is greater the larger the jump is, thus the larger the derivative A3. Negative jumps are more strongly weighted than positive jumps. The following effects result:

- The computer 4 reduces the derivative-specific weighting factor W3 when it determines a derivative A3 different than zero beforehand, thus for an intermediate pixel 6' that is arranged between an initial pixel 6" and the presently considered pixel 6. The initial pixel 6" is on an edge of the image B, and a vector V from the initial pixel 6" to the pixel 6 under consideration corresponds with the respective derivative direction R3.

- The weighting factor W3 is reduced more the larger the jump (thus the magnitude of the derivative A3) for the intermediate pixel 6'.

- Given equal magnitude of the derivative A3 for the intermediate pixel 6', the weighting factor W3 is more significantly reduced given a negative derivative A3 for the intermediate pixel 6' than given a positive derivative A3 for the intermediate pixel 6'.

To detect the derivative directions in step S4 of Figure 3, a method is executed that is subsequently explained in detail in connection with Figure 6.

According to Figure 6, a Hough transformation is first implemented by the computer 4 in a step S22 using the derivative values z', and thus a transformed image is determined in Hough space. This image, called the Hough-transformed H,

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exhibits variables ϑ, ρ. It is subsequently designated as $H(\vartheta, \rho)$. ϑ and ρ are an angle variable and a distance variable, respectively. The angle variable ϑ specifies which angle a straight line makes with the main axis x. The distance variable ρ specifies the distance ρ this straight line exhibits from the intersection point of the main axes x, y. The value of H at the point (ϑ, ρ) specifies how strongly this straight line is present in the derivative image z'.

The Hough transformation as such is generally known. It is therefore not gone into in more detail in the following.

In a step S23, the computer 4 determines the maximum $Hmax(\vartheta)$ of the Hough-transformed $H(\vartheta, \rho)$ for each value of the angle variables ϑ. This one-dimensional function $Hmax(\vartheta)$ is subsequently designated as an angle maximum.

In a step S24, the computer 4 determines a sum maximum $HS(\vartheta)$ according to the formula

$$HS(\vartheta) = Hmax(\vartheta) + Hmax(\vartheta + \pi/2).$$

To detect the diaphragm edges 8, the computer 4 thus detects respective groups of detected image edges 8, 9 that with one another form the known angle of 90° (or $\pi/2$). For the groups of image edges 8, 9 thus detected, the computer 4 forms a sum value of the derivative values z' or of the corresponding Hough-transformed H.

In a step S25, the computer 4 determines the value of the angle variables ϑ at which the sum maximum HS is maximal. For this value of the angle variables ϑ, in a step S26 the computer 4 then seeks values $\rho1$, $\rho2$ of the distance variables ρ in which the amount of the difference of the distance variables $\rho1$, $\rho2$ is at least as large as a minimum distance ρmin, and in which the value of the Hough-transformed H below the angle ϑ is greater than a threshold SW. It thus tests whether two

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parallel image edges 8, 9 that exhibit a minimum separation ρmin from one another exist below the angle ϑ. In step S26, the computer 4 could, for example, determine the separation values ρ1, ρ2 such that the sum of the Hough-transformed $H(\vartheta,ρ1)+H(\vartheta,ρ2)$ is maximal. Alternatively, it could, for example, also maximize the difference of the distance values ρ1, ρ2.

When, the computer 4 has found such a distance variable ρ1, ρ2 in step S26, it branches from a step S27 to a step S28. In step S28, the computer 4 determines in an analogous manner distance values ρ3, ρ4 in which the amount of the difference of the distance values ρ3, ρ4 is likewise at least as large as the minimal distance ρmin, and in which the value of the Hough-transformed H for the angle variable $\vartheta + π/2$ is greater than the threshold SW. In a step S29, the computer 4 again checks whether it could find such distance variables ρ3, ρ4. When this occurs, it has detected the sought diaphragm edges 8.

If the testing in one of the steps S27, S29 is negative, step S30 is executed. In step S30, the computer 4 determines the next-best value of the angle variables ϑ, thus the value of the angle variables ϑ in which the sum maximum HS assumes the next lowest value. It then jumps back to step S26.

The method according to Figure 6 is thus implemented until four image edges 8, 9 are detected which fulfill the required diaphragm structure (rectangle) and exhibit a sufficient strength. The computer 4 thereby checks the groups of image edges 8, 9 in the series of sum values HS, by testing groups with larger sum values before groups with lower sum values.

In practice, the diaphragm edges 8 often do not exactly form a rectangle, but do so only approximately. The angle specification (0° or 90°) therefore ensues in practice only in the framework of a small uncertainty that is generally mostly in the

range of a few degrees, for example +/- 3° or +/- 5°. This angle uncertainty is true both for the parallelism of the diaphragm edges 8 and for the orthogonality of the diaphragm edges 8.

Naturally, the inventive detection method is also not limited to rectangular diaphragm structures. The diaphragm structures can be of other types. For example, without anything further a search for a regular hexagon or for a triangle is possible. Given specification of a square or another even-numbered regular polygon (for example hexagon, octagon, ...), it can furthermore be considered that the distance of the diaphragm edges 8 parallel to one another must be constant for all such pairs.

By the inventive detection method, weekly contrasting diaphragm edges 8 can also be automatically detected with a computer with a probability limited in terms of reliability. The consideration of the known diaphragm structure enables the largely predominant part of the possible error recognition to be excluded based on plausibility tests.

Although modifications and changes may be suggested by those skilled in the art, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications as reasonably and properly come within the scope of their contribution to the art.